

## The coproduction of electric mobility: selectivity, conformity and fragmentation in the sociotechnical acceptance of vehicle-to-grid (V2G) standards

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# **The coproduction of electric mobility: Selectivity, conformity and fragmentation in the sociotechnical acceptance of vehicle-to-grid (V2G) standards**

## **1 Introduction**

Standards structure our energy systems and ‘often exert invisible power over individuals; they organize our reality, how we move, who we are, what we eat, and take on an objectivity which disguises their reality creating role (Power, 2014, p. 113).’<sup>1</sup> They create shared understandings and coordinate actions, often without direct enforcement or membership obligations, and as such they fill the space between international regulation, national laws, company processes and consumer behaviour. While there is quite some socio-political work on standards (Brunsson et al., 2012; Busch, 2011; Bush et al., 2015; Loconto, 2015; Power, 2014; Timmermans and Epstein, 2010), the energy literature sees technical standards, as opposed to environmental standards like fuel saving classes, often discussed on their technical merit, but not as a political phenomenon (Huang et al., 2016; Pei et al., 2016; yet see Ho and O’Sullivan, 2017). Not surprisingly, a political or sociotechnical analysis of electric vehicle standards is even more uncommon. The exception is work by Bakker et al. (2015) and Brown et al. (2010) on the standardization of visible and tangible charger plugs.

This paper instead explores and reviews how a single, almost invisible and highly technical communication standard dealing with vehicle-to-grid (V2G) technology is being coproduced and implemented in divergent ways across Asia, Europe, and North America up until 2016.<sup>2</sup> Specifically, the paper introduces ISO 15118 from the joint International Standardization Organization (ISO) and the International Electrotechnical Commission (IEC), and describes how this standard is adapted in China, the United States of America (USA), Denmark and the Netherlands. It also explores the network of standards to which it is connected and draws on various literatures to

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<sup>1</sup> CAN - Controller Area Network; DSO – Distribution Service Operator; EV – electric vehicle; EVSE – Electric Vehicle Supply Equipment (‘the charger’); IEC - International Electrotechnical Commission; ISO – International Standardization Organization; OCHP - Open Clearing House Protocol; OCPP - Open Charging Point Protocol; OEM – Original Equipment Manufacturer (‘car producer’); PEVs – Pluggable Electric Vehicles; PLC – Power Line Communication; RFID – Radio Frequency Identification; SAE - Society of Automotive Engineers; STS - Science & Technology Studies; V2G – vehicle-to-grid.

<sup>2</sup> As such this paper deals with the first version of ISO 15118. Since the finalization of this study there has been a lot of work on the second version of ISO 15118, which is more comprehensible and detailed and has more international support.

understand the role that an invisible standard like ISO 15118 plays in society. We conclude that the initial implementation and acceptance of ISO 15118 varies socio-culturally from strategic selectivity in China, conformity and compliance in Europe, and fragmentation in the United States.

Assessing ISO 15118 is important as it structures the high-level communication between electric vehicles (EVs) and the charger or Electric Vehicle Supply Equipment (EVSE). Through this high-level communication, ISO 15118 enables a novel technology known as V2G. An automobile capable of V2G interaction, sometimes referred to as ‘mobile energy’ or ‘smart charging,’ mates an automobile with the electric utility system (Kempton and Tomić, 2005a, 2005b) and allows for bidirectional flows of power. As a communication standard, ISO 15118 aims to standardize the automatic authentication, authorization, flexible load control and billing procedure between EVs and EVSEs (ISO, 2013; Mültin and Schmeck, 2014). As such it allows for controlled charging and the back feeding of power to the grid, which in turn enables EV batteries to be used, potentially, for frequency regulation, spinning reserve, peak shaving and other grid services. This intelligent, two-way communication between the electricity grid (operators and markets) and the vehicle (and driver) therefore supports utilities in their task to manage electricity resources and empowers vehicle owners to reduce the lifecycle costs of their cars by selling power back to the grid.

This paper’s focus on a V2G standard thus informs current debates and attempts to promote low-carbon electric mobility (Sovacool et al., 2017). The introduction of ISO 15118 for example starts with a reference to the ‘pending energy crisis and the necessity to reduce greenhouse gas emissions’ and then continues to argue for standards to enable the shift to electric mobility (ISO, 2013, p. v). As mentioned above, standards provide the shared understanding of industries and their networks to increase economic efficiency at the production side and convenience and safety on the consumption side (Brown et al., 2010). Thus, they influence the future direction, speed and costs of sociotechnical developments, including the introduction of EV technologies and the resulting substitution of fossil fuels and storage for intermittent energy sources. In addition, standards influence the environmental impact of EVs themselves, as they offer guidance on technology and safety requirements, product quality and business performance measurements, and energy efficiency and environmental requirements (Gerst and Gao, 2016).

As we demonstrate in this article, this process is not merely a technical phenomenon but instead a political process that ‘coproduces’ humans and things (Jasanoff, 2004). Within the standardization literature Busch (2011, p. 3) makes a similar point when he argues that standards are ‘the recipes by which we create realities’. Likewise, Timmermans & Epstein (2010, p. 70) claim that one needs to be ‘be attentive to the normative dimensions of standardization as a powerful, sometimes subtle, and sometimes not-so-subtle means of organizing modern life.’ We thus argue that a variety of social practices—in this case, divergent ways of implementation shaped by political, economic and cultural contexts — are woven into the evolution of emergent V2G standards, even one as specific and technical as ISO 15118. Or as Taylor et al. (2014, p. 33) write, models and standards can operate as ‘boundary objects’ that become ‘not only based on mathematical representations of the world, but are also shaped by, and play a role in shaping, the social world in which they are embedded.’

In short, the paper contributes to the electric mobility literature as it offers a first nontechnical introduction and explanation of ISO 15118 and other V2G communication and charging standards. By drawing on the coproduction and the standardization literature, the paper further contributes to the low-carbon energy literature by showcasing how even such invisible and highly technical standards are politically mediated and have political effects, and are therefore valid and necessary objects of study.

## **2 Research concepts and case selection**

This section introduces the research concepts that are used, the content of ISO 15118 and summarizes the case selection.

### **2.1 Coproduct and the socio-technicality of standards**

In terms of a conceptual framework, this study is situated at the nexus of the academic literature on innovation studies, science and technology studies, and the standardization literature. Specifically, it employs the interdisciplinary concept of ‘coproduction’ to illustrate how technical standards coevolve with other elements such as social values and organizational strategies. As Jasanoff writes (2004, p. 2), ‘coproduction is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from

the ways we choose to live in it.’ In short: standards co-create a technical or scientific order alongside a social or cultural one. Viewing standards this way—as subjective, coproduced elements constantly in flux rather than objective elements that are permanently stable—does two noteworthy things. It firstly reveals how standards become entangled with social norms and hierarchies and the politics of setting up standards and the political effects that result from them. It secondly rejects scientific determinism and shows that standards are not an unmediated reflection of science and engineering, but instead are material embodiments and products of social work.

Though the concept of coproduction has been already applied to a variety of fields – physics and the detection of gravitational waves (Collins, 1985), vertebrate zoology (Star and Griesemer, 1989), emergency medicine (Timmermans and Berg, 1997), genome diversity research (Reardon, 2001), climate and atmospheric science (Miller, 2005), psychiatry (Brodwin, 2008), forest management (Swedlow, 2012), neuroscience (Pickersgill, 2012), and the process of metrology itself (Mallard, 1998) – it has been less applied to the automotive or engineering realm. Furthermore, no research (to our knowledge) has applied it to quality control standards in business, nor has it been extended to the automotive or transport sector or especially electric mobility or V2G.

This is remarkable as the notion of coproduction fits nicely with the reigning understanding of standards in the literature where standardization refers to ‘a process of constructing uniformities across time and space, through the generation of agreed-upon rules (Timmermans and Epstein, 2010, p. 71; building on Bowker and Star, 2000). In this process, ‘[s]tandards can emerge as the consequence of consensus, the imposition of authority, or a combination of both (Russell, 2005, p. 1).’ The resulting standards are rules for ‘common use’ that coordinate relations between private parties through standardization (Botzem and Dobusch, 2012, p. 738; Brunsson et al., 2012) or actually generate distinctions and rankings through standardized differentiation (Busch, 2011). Irrespective whether they are used for coordination or differentiation, standards are thus less strict than formal regulations, laws and national boundaries but simultaneously more structured than shared social norms. At the same time, they are inherently dynamic: they evolve and are nested in other standards, unevenly distributed, and often voluntary as they mainly work indirectly through ‘coercive, normative and mimetic isomorphic pressures’ (Brunsson et al., 2012, p. 618; Lampland and Star, 2009). In other words, standards are part of a continuous (re)negotiated political process.

In this respect, ISO 15118 offers an interesting case for two reasons. First, it is a highly technical standard that not many people are, nor will they ever, be aware of because it is not a tangible standard, like the charger types discussed in Bakker et al. (2015). Second, it is a relatively new standard. Even though ISO 15118 is approved by the main international standardization body, it is still in need of national and local adaptation by both national standardization organizations and related car and charging industries. The focus of this paper is therefore not only on *whether* these standards are integrated but also on the constant negotiation and feedback behind their implementation and the differences that emerge in this process (Botzem and Dobusch, 2012, p. 741).

## 2.2 The ISO 15118 standard

In terms of a brief background, work began in 2009 when the ISO/IEC 15118 Joint Working Group was formed to define a communication standard for the charging of EVs. One that would be able to deal with both Alternating Current (AC) and Direct Current (DC) charging levels and incorporate a V2G option (see use case F5 in ISO, 2013, p. 40; Schmutzler et al., 2013). ISO 15118 builds on IEC 61851, a more basic communication standard (see Table 1), by adding Power Line Communication (PLC) to increase the communication features between a car and its charger (Martinenas et al., 2016). The standard consists of eight parts. The first three of these are published, while the others are in various stages of development and draft. The eight parts of ISO 15118 can be summarized respectively as dealing with: 1) general information and use-case definition; 2) network and application protocol requirements; 3) wired physical and data link layer requirements; 4) network and application protocol conformance tests; 5) physical layer and data link layer conformance test; and 6-8) wireless communication (ISO, 2013).

Content wise, ISO 15118 lists the technical requirements and communication protocols that enable bidirectional communication between the electric vehicle communication controller in the EV and the supply equipment communication controller in the EVSE. At present this communication takes place directly along the control line which is part of the wire between the EV and EVSE, but in the future this could also be wireless. Based on its content and with the help of the four categories of standards of Timmermans & Epstein (2010), ISO 15118 is not a performance standard, but can be categorized as a terminological, design, and procedural standard

because it simultaneously structures the communication process (procedural), details the specifications of the necessary components (design), and clarifies definitions and roles (terminological).

Furthermore, ISO 15118 should be seen as a nested standard. This is something Filipović (2013) describes when he talks about an ‘ecosystem’ geared towards the ‘systemic standardization’ of electric mobility. A standard like ISO 15118 might appear to stand on its own, but only works in relations to a broader network that consists of institutions, agents, technology, strategies, social norms *and* other standards. In this network, ISO 15118 focusses specifically on the first communication tier of e-mobility: the connection between the EV and the EVSE. The second tier of communication deals with the communication between the EVSE and their servers, while the third tier deals with the communication between the servers of different EVSE operators to allow for roaming services so that an EV driver can charge at the infrastructure of multiple operators (Buamod et al., 2015, p. 5). Table 1 provides a brief overview of the main standards that are discussed in this article.

*Table 1: Overview of the communication standards behind electric mobility charging mentioned in this article*

<b>Standard</b>	<b>Focus</b>	<b>Description</b>	<b>Used/intended to be used</b>
ISO 15118 (-2015 1-8)	EV – EVSE	A de-jure standard. Adding high-level communication to ISO 61851, incl. standardized automatic authentication, authorization, load control and billing procedures. Based on PLC with a HomePlug Green PHY communication protocol.	Globally
SAE J2847 / 1-3	EV – EVSE	A de-jure standard with three parts. Of these parts, part 1 (AC charging) and 3 (V2G) are based on SEP 2.0, and part 2 (unidirectional DC charging) is based on ISO 15118 and PLC.	United States
CHAdeMO	EV – EVSE	A de-facto, by now globally recognized, DC Quick charge standard, which builds on ISO 61851 but then uses alternative hardware and communication protocols based on Controller Area Network (CAN) not PLC.	Japan/Korea and globally through CHAdeMO charging infrastructure
GB/T 27930 (-2015)	EV-EVSE	A de-jure standard. V2G aspect primarily based on SAE J2847, but with CAN based communication protocol following the Original Equipment Manufacturer (OEM) practice of using ISO 11898.	China
ISO 61850 & ISO 61851	EVSE - Grid	A de-jure standard. Used for low level (automated) grid communication between and towards electricity substations. Focuses on voltage, frequency and duty cycles.	Globally

OCCP	EVSE – EVSE Operator	A de-facto standard. Structures data streams between EVSEs and control servers.	Open, Western-Europe but spreading
OCHP	Between EVSE operators	A de-facto standard. Structures data streams between EVSE operators and an international clearinghouse to allow for interoperability between different charging station operators.	Open, currently Western-Europe
SEP 2.0	Smart grid	Developed by the ZigBee Alliance. General PLC based machine-to-machine communication protocol for energy appliances (incl. EVs) within a smart grid.	United States

Source: Authors

Despite its novelty and importance, ISO 15118 is not completely devoid of controversy. One criticism of ISO 15118 is that the mandatory security measures are insufficient (Buamod et al., 2015; Höfer, 2013; Lee et al., 2014). For example, Lee et al. (2014, p. 4) criticize ISO 15118 for having several ‘unsatisfactory security requirements’ related to ‘authenticity, data integrity, confidentiality, privacy protection, non-repudiation and availability.’ Saxena & Choi (2016) similarly note how according to ISO 15118-2 only unilateral authentication (i.e., server side authentication) is mandatory, while mutual authentication (EV-side authentication) is optional, despite the additional security the latter would provide against redirection and impersonation attacks. Even though several different systems have been proposed to reduce security risks, increase an individual’s privacy and guarantee data authenticity (Chen et al., 2015; Höfer, 2013; Lee et al., 2014; Saxena and Choi, 2016), none of these have so far been accepted into the standard, nor implemented in real-world projects.

### 2.3 Case selection

For the study into the acceptance and institutionalization of ISO 15118 we have selected four representative countries for examination: China, the USA and two European countries, Denmark and the Netherlands. All of these countries make strong inroads into electric mobility. Both in terms of the absolute or relative number of acquired personal pluggable electric vehicles (PEVs) and related infrastructure (see Table 2), and in terms of innovation and public support for green mobility in general. Furthermore, both the USA, Denmark and the Netherlands are among the first countries with active V2G projects.



Table 2: Number of PEV and charger units in China, USA, The Netherlands and Denmark

End of year	Sold PEVs	Total PEVs	Public charging infrastructure		Market share (new vehicles)	Total share of fleet
			Slow	Fast		
<b>China (2015)</b>	207.382 <sup>a</sup>	312.290 <sup>a</sup>	46.657 <sup>a</sup>	12.101 <sup>a</sup>	1,0% <sup>a</sup>	0,18%
<b>China (2016)</b>	351.861 <sup>f</sup>	645.708 <sup>c</sup>	100.000 <sup>g</sup>		1,45%	0,33%
<b>USA (2015)</b>	113.870 <sup>a</sup>	404.090 <sup>a</sup>	28.150 <sup>a</sup>	3524 <sup>a</sup>	0,7% <sup>a</sup>	0,153%
<b>USA (2016)</b>	157.130 <sup>c</sup>	570.187 <sup>c</sup>	35.456	5.529	0,9% <sup>a</sup>	0,2%
<b>Netherlands (2015)</b>	43.769 <sup>d</sup>	87.531 <sup>d</sup>	17.786 <sup>d</sup>	465 <sup>d</sup>	9,7% <sup>d</sup>	1,1%
<b>Netherlands (2016)</b>	24.477 <sup>d</sup>	112.008 <sup>d</sup>	26.088 <sup>d</sup>	612 <sup>d</sup>	6,4% <sup>d</sup>	1,38%
<b>Denmark (2015)</b>	5.298 <sup>b</sup>	8.480 <sup>e</sup>	1630 <sup>e</sup>	421 <sup>e</sup>	1,9% <sup>e</sup>	0,303%
<b>Denmark (2016)</b>	2.063 <sup>b</sup>	9.276 <sup>e</sup>	2114 <sup>e</sup>	422 <sup>e</sup>	0,5% <sup>e</sup>	0,324%

Source: Authors. Notes: <sup>a</sup> IEA (2016); <sup>b</sup> European Automobile Manufacturers Association (2017); <sup>c</sup> Cobb (2017); <sup>d</sup> RVO (2017); <sup>e</sup> EAFO (2017); <sup>f</sup> Pontes (2017); <sup>g</sup> Wang (2017)

Then again, in three of the cases the incentives for EVs are being reduced. In China, the 13th Five-Year Plan sets a target of 5 million EVs on the road by 2020 (State Council, 2016). To reach this goal, the government provides a range of fiscal subsidies in order to promote technological innovation, develop charging facilities and stimulate the consumption of EVs. Following notions of fraud with the massive incentives in 2015 (up to 14,000 dollars by state and local governments), the national and local governments have withheld some of their support for electrified public transportation. Similar stories can be found in Denmark and the Netherlands. In Denmark the government decided to phase out the purchase tax exemption on EVs as of January 2016 (a decision that inflates the 2015 sales number, see: Nordic Energy Research and IEA, 2016; Thure, 2015). In the Netherlands, the public support policies were adjusted as well, among others by increasing the CO<sub>2</sub> emission requirements for tax exemptions, which affects hybrids and plugable hybrids (Ministry of Finance, 2015).

Such government incentives only tell part of the story. The next two sections, respectively, present the adaptation and institutional context of ISO 15118 in each of the regions and then discusses what this means for electric mobility. In terms of methodology, these cases are based on a desk study that focussed on publicly available sources up to 2016 in both English, Chinese, Dutch and Danish describing 1) how standards are set, 2) whether there are V2G standards and, if so, what their content is, and 3) whether the companies working on electric mobility in these countries adhere to these standards.

### 3 Results: A tale of three implementation strategies

This section describes the implementation of ISO 15118 in the four countries, from the strategic and functional selectivity of standard implementation in China, the aggressive conformity and compliance in the small European countries and the fragmented acceptance of ISO 15118 that can be observed in the USA.

#### 3.1 Strategic selectivity in China

Despite the emergence of a culture of electric mobility, membership of ISO, and the presence of 75 EV standards (with another 77 standards under discussion (Wu, 2014)), China does not have a national V2G standard based on ISO 15118. Instead, China released its own national standard, GB/T 27930, in December 2015. This national standard similarly deals with communication protocols between off-board chargers and battery management systems for EVs (SAC, 2015c). Although GB/T 27930 is based on insights from both the ISO and American Society of Automotive Engineers (SAE), it appears that in this case the SAE standards were a better source of inspiration to structure the technological requirements (see its predecessor SAC, 2015a). More important, however, is that the Chinese standard is based on Controller Area Network (CAN) instead of the PLC behind ISO 15118. This seems to be given by the domestic automotive industry where CAN protocols are common (following ISO 11898). Then again, in relation to the connector and charging architecture the national Chinese standards are often based on ISO/IEC standards (SAC, 2015c). Furthermore, the Chinese EV subcommittee has participated in the international discussions about ISO 15118 since 2011. There is thus not a clear prevalence for one over the other. Instead, the standards are decided on in a case-by-case situation and co-evolve in line with domestic markets and technological developments.

Li (2011) notes how automobile manufactures in Europe were anxious about the fact that GB/T 27930 was not based on ISO 15118, as they feared that different standards on the communication protocol would result in different technologies, which would lead to unnecessary investments in R&D. Two remarks can be made in this respect. First, the procedure of standard setting in China is different from that in other countries. Whereas in the other countries the standard setting bodies are independent accreditation organizations, in China they are official

administrative departments and hence part of the government.<sup>3</sup> What is more, the standards are ultimately issued and thus approved by the State Council (the highest administration organ in China). Second, while the government might be selective regarding ISO 15118, the strength of an international standard shows even in China when one looks at some of the companies involved. Several multinationals active in China (Maxim Integrated, 2016; Neusoft, 2016; Phoenix Contact, 2016) and international active Chinese companies (Polelink, 2016) are taking ISO 15118 into account and are actively designing their products under its guidance. So, while the standards committee has decided not to follow ISO 15118 (for now), the standard is still implemented and translated by internationally active companies.

### 3.2 Conformity and compliance in Europe

In the two small European countries, the position regarding ISO 15118 can best be described as conformity and compliance. In fact, both Denmark and the Netherlands have implemented ISO 15118 rather quickly, in the Danish case even before its official acceptance, following a common desire to implement a global standard.

For example, the Danish Standard Association first accepted the ISO 15118 as a national standard under the provision DS/ISO 15118-1:2013 (Dansk Standard, 2013) when it had yet to be accepted as a regional (European) standard. This desire seems to follow the research projects in Denmark. For example, in 2009 one of the main partners behind the Danish *EDISON* project, the company Eurisco, built an operational platform to test the interoperability between a number of charging systems and EVs (EDISON, 2013, 2011). This platform already included drafts of ISO 15118 in its design, as it was recognized that the country needed standardized ‘communication between the different operators, charging equipment, electric vehicle and users (EDISON, 2011, p. 201).’ In 2013, the subsequent *Nikola* project started to investigate the services between EVs and the power system. This project also focused on control and communication as its main goal was to ‘tie its technology development to current European and world-wide standardization efforts, especially applicable standards such as ISO 15118 and IEC 61851 (Andersen et al., 2014, p. 5).’ All this before July 2015, when the European Committee

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<sup>3</sup> The National Technical Committee of Auto Standardization of the People’s Republic of China is a national Standards Development Organization which is subordinated to the Ministry of Industry and Information Technology and the Standardization Administration of China (SAC).

for Standardization (CEN) accepted ISO 15118-2013 and bound all its members to it (including Denmark and the Netherlands) effectively giving ISO 15118 the status of a national standard across the EU by February 2016 (Dansk Standard, 2015).

Whereas the Danish collaboration seems to originate from research projects, the Dutch motivation for standardization instead seems to result from the electricity grid side. Very early on, the nine Distribution System Operators (DSOs) in the Netherlands decided to cooperate in the subsidiary *E-laad* (currently ElaadNL) and agreed on the Menneke plug for local charging. A plug which has since been made the EU standard as well (Bakker, 2013; ElaadNL, 2016). The initial dominant position and cooperative nature of *E-laad* is still valid and has led to a fast growing interoperable charging infrastructure where EV drivers can choose their service provider independently of the EVSE operator (Boekema et al., 2010). The close cooperation in the Netherlands between the DSOs and EVSE suppliers and operators, in turn falls under the Formula E-Team: a more general program wherein national and subnational governments, companies, nongovernmental organizations and research facilities cooperate with the aim of supporting the move to electric mobility.

The parties involved in Dutch electric mobility therefore seem to agree on a shared approach (Eveleens et al., 2015, p. 26) and on the importance of standards. For example, it was the Dutch government which financially supported the creation of a standardization committee with free membership for potential stakeholders in order to promote domestic standardization and to have a seat and a voice at international standardization bodies (Michel, 2012, p. 29). At the same time, some Dutch actors deviate from this agreement, often for practical reasons. For instance, one of the first V2G test projects in the Netherlands, *Smart Solar Charging* in the city of Utrecht (Storage4all, 2015; Smart Solar Charging, 2015), was originally based on the CHAdeMO standard due to the limited availability of other reverse flow capable cars (they worked with the Nissan Leaf, see: Storage4all, 2015, p. 13). Consequently, their project is incompatible with ISO 15118 (Nauck, 2014).<sup>4</sup> A new, non-CHAdeMO, EVSE from the Smart Solar Charging consortium is stated to be V2G capable and has recently been approved by

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<sup>4</sup> A recent study by the IEA in fact stated that the CHAdeMO standard is currently the de facto standard for V2G projects, a conclusion drawn on the number of bidirectional chargers available: more than 3,000 in Japan alone (IA-HEV, 2016, p. 118). However, it also highlights the weakness of CHAdeMO for electricity utilities, namely the time delay in the protocol that inhibits some of the benefits of direct control of battery storage.

*ElaadNL*, but is currently used for controlled charging only, again, due to a lack of V2G capable EVs (Zwiers, 2016).

In general, the debates in both Denmark and the Netherlands are not focused on competing standards, but rather emphasize how to further implement and develop ISO 15118. This includes a focus on the integration of ISO 15118 in broader smart charging techniques and its connection with the back office software that is necessary to enable commercial transactions across companies and regions. Both countries have also essentially obligated themselves to adopt and translate international and European standards as soon as they are published. However, this formalization does not seem necessary in this case given the observed need for standardization in both countries. A need that might be explained by both of them being small countries without large car manufacturers. This not only removes the political cloud of the latter (Michel, 2012), but also makes it easier to collaborate and communicate due to the limited number of parties involved.

### 3.3 Fragmentation in the United States

Since ISO 15118 is a novel standard still under development, a process of 7 to 8 years in total, and given the long lead times for car producers even if they decide to adapt ISO 15118 for new cars (CEC, 2016), there has not been a long history of implementation in the USA. Indeed, the controversy in the USA is *which* communication standard to utilize. Unlike the two smaller European countries with their clear acceptance of ISO 15118, the USA does not have a single standard in use. To be more precise, the question is to what extent ISO 15118 is encapsulated under the more general Smart Energy Profile 2.0 (SEP 2.0) standard for smart grids or whether these two standards compete.

The USA automotive standards body, the SAE, has developed a parallel standard of communication known as SAE J2847. The first part of this standard, SAE J2847/1, is based on SEP 2.0 which provides guidelines for price-based smart charging, demand response load control, and flow reservation for (unidirectional) AC charging (Chen et al., 2015). SEP 2.0 has already been used to control charging in a pilot project utilizing a Chrysler pluggable hybrid and is funded by the US Department of Energy (Chen et al., 2015). In turn, the second

part, SAE J2847/2, is based on ISO 15118 and defines a communication protocol for the off-board unidirectional DC charging of an EV. The last part, SAE J2847/3, uses SEP 2.0 as a basis for communication for defining EVs as a distributed energy resource, which includes bidirectional capabilities. There is thus some overlap between SAE J2847/2 and ISO 15118, especially on charging control, but for bidirectional charging SEP 2.0 and ISO 15118 offer two different communication standards.

While SEP 2.0 is the official SAE standard of communication, the implementation of communication protocols in the USA has been quite varied. For example, a pilot project at the University of California, San Diego will implement ISO 15118 as its communication protocol (Margoni, 2015). In another example, a V2G project at the Los Angeles Air Force Base performs ancillary services using another communication protocol, Open Automated Demand Response 2.0b (Chen et al., 2015), in addition to SEP 2.0 (Markel et al., 2015). As the name implies, this communication protocol is geared towards automating demand response, and less towards other V2G services such as frequency regulation. The first global commercial V2G pilot project at the University of Delaware uses neither SEP2 nor ISO 15118, but instead uses communication based on Annex D of IEC 61851-1 while utilizing the control pilot line (Markel et al., 2015).

There have been efforts to integrate the various aforementioned communication protocols into a single integrative system (Chen et al., 2015; Schmutzler et al., 2013) and there are strong signs that the SAE and updated ISO 15118 standards will be successfully harmonized (CEC, 2016), but in the interim the bidirectional communication standards in the USA remain uncertain. Indeed, as shown above, some V2G projects do not utilize any communication standard, but rather develop their own system (Gleason, 2013) despite the need for a standard to increase scalability and interoperability. In the USA, ISO 15118 is thus facing resistance as some agents prefer direct EV-EVSE communication protocols (ISO 15118) and others prefer a communication protocol that sees EVs (and their V2G capacity) as an aspect of a smart home with many more appliances (SEP 2.0).

#### 4 Discussion and analysis: Implications for energy studies

So far, the paper has touched on the standard itself and its implementation in three different regions, as summarized in Table 3. This section proceeds to discuss the distinctions between these regions and then builds on the standardization and STS literature to assess the value of these differences.

*Table 3: Summary of V2G standard implementation strategies across Asia, Europe, and North America*

	<b>Standard</b>	<b>Main advocate/proponent</b>	<b>Reason</b>
<b>China</b>	GB/T 27930	State	Building on role of CAN protocols in OEM industry
<b>USA</b>	SAE J2847 or SEP 2.0	SAE (automotive) for SAE J2847 and smart grid developers for SEP 2.0	Searching for an integrated approach
<b>The Netherlands and Denmark</b>	ISO 15118	Grid operators, charger companies and research institutes	Reducing investment risk in charging infrastructure

Source: Authors

##### 4.1 Dynamic interpretation

Although ISO 15118 is a globally accepted standard, it has so far not been uniformly implemented. Part of this fragmentation follows the relative recent publication of ISO 15118, but there seems to be a difference in approach between the smaller European countries and world powers like China and the USA. Where the smaller European countries have accepted ISO 15118 and are working through its technical aspects as they await commercially available V2G capable EVs, the larger countries instead have been developing their own standards. Interestingly, in each of the cases there are private parties which seem less inclined or unable for practical reasons to follow the official standards that are in place. In China, private companies utilize ISO 15118 while in the USA quite a number of companies and projects base their work on other standards.

These different approaches to ISO 15118 might be explained by two main variables: the size of their domestic markets and the presence of globally operating car manufacturers. Unfortunately, the current case selection prevents a discussion on the importance of the latter, as it does not include a small country with a large car manufacturing infrastructure. What the cases do show is the importance of size and scale. The size of the Chinese and USA markets provides incentives for domestic standards, while EU law and the dependence on

international markets in the Netherlands and Denmark have made it possible for the latter to agree on close cooperation at the network side very early on – accepting ISO 15118 even before its official release. This countrywide cooperative nature plays a major role in the acceptance and implementation of standardized technology and accompanying regulations. Yet the above also showed that these countries are dependent on the international car market for V2G capable vehicles.

The variation in standardization thus reminds us that the traditional narrative of standards as ‘solutions to a market failure,’ stewards of coordination for ‘dispersed producers and providers,’ or mechanisms that ‘reduce transaction costs’ (Kindleberger, 1983; Lecraw, 1984) is replaced by one emphasizing their normative and social nature exercised within political processes. Standards emerge and evolve based on continual compromise, often creating tension between individual interests and shared rules of behaviour. At this intersection, standards emerge and organize life. For political scientists, standards serve as instruments of power by differentiating between acceptable or preferred options and those that are not (Busch, 2011; Gorur, 2013). In some cases, standards actively exclude, as when food quality and food production standards exclude low quality or unsustainably produced food from the markets (Loconto, 2015; Ouma Stefan, 2010), although Beniger (1986) for example also compellingly wrote how shop standards in the early twentieth century were intended to *prevent* products from being too high in quality, to socialize consumers to accept lower quality goods and improve profit margins. Not that we argue that ISO 15118 is doing this, but merely to show that standards should be viewed as sites of conflict, given that they are ‘heavily implicated in defining multiple spatial and temporary categories (Gaggio, 2002, p. 294).’ Basically, standards always privilege some types of knowledge or ways of doing things above others and, as they can be hegemonic, ambiguous, and heterogeneous, require social as well as technical meaning.

#### 4.2 Control and user engagement

A large part of this ‘conflict’ is related to vested interests and path dependent investments of one company or consortium over another. In fact, we see this in the statements from car manufacturers to a public input meeting from the California Energy Commission (CEC, 2016). Where most of the American and European representatives showed their support for ISO 15118 and mentioned that they are deploying it in their new vehicle models, one



German brand cautioned against a single obligatory standard; primarily because it had developed an alternative cloud-based way to control and communicate the charging of its EVs. Here however, we would like to draw attention to the deeper social and ethical effects of standards by focussing on the pre-scripted assumptions about users that are built into ISO 15118, in line with early STS work on materiality. Authors like Pfaffenberger (1992) and Winner (1980) argue that artefacts or technologies materialize a particular world based on the implicit and explicit assumptions of its designers, including assumptions on the intended users. For example, Winner (1980) discusses the low-hanging overpasses on Long Island that were limited in height and thereby allowed cars to pass but not buses, consequently privileging the predominantly white car-owning class.

Less extreme, ISO 15118 does have its own assumptions. For example, one inherent materialized result of ISO 15118 is the redundancy of RFID cards (and other forms of activation) that are currently used to communicate the identification, authorization and payment details of a charging session. ISO 15118 aims to do this through a plug-and charge service. In other words, it makes RFID cards redundant and forces EV drivers to approach EVSEs and their operators differently (Mültin and Schmeck, 2014). Where the RFID cards are used as both identification and authorization of the trade and its payment, this will be replaced by the act of plugging-in together with earlier authorizations and contractual agreements between the driver, the EVSE operator, the roaming companies and the electricity suppliers. The idea here is that in reducing the role of the consumer to plugging-in (with wireless charging even this is no longer necessary) the drivers' life is made easier and less prone to complicate the transaction.

While there is nothing onerous about this and consumers still have to partake in the actual action to charge their EV by either plugging-in or by notifying their operators of their special travel plans (in case of smart charging or V2G), one could provocatively argue that ISO 15118 is scripted with a pampered and undependable consumer. As ISO 15118 stipulates: 'Whenever the term 'USER' is used in this standard as the subject of a requirement this is rather meant to provide guidance for the implementer of the standard how a USER can behave and *how a user should be guided by any means* [rather] than defining the exact behaviour of the USER (ISO, 2013, p. 14 italics added).' Even though this clearly states that there is no explicit intent to define the behaviour of EV drivers, we argue that the overall goal (to charge in the benefit of the grid) does so anyway. With the standard comes the

assumption that drivers themselves are incapable and unreliable to take actions in the way that the system requires and hence *should be guided by any means*. A similar assumption returns in research on charging patterns where EV drivers are seen and modelled as consumers who plug-in when they come home from work – all at the same time (Alonso et al., 2014). To counter this, the system is automated and the resulting system preconditions ‘consumers’ to interact with it as its designers see fit.

In other words, a shared or tacit understanding – rightly or wrongly – structures how parties engage with the communication between EVs and EVSEs, and these basic assumptions drive the need to control the process of charging and discharging. ISO 15118 builds on these assumptions and is instantiated on the desire to standardize the connection between two previously unconnected and unfamiliar systems: that of automobility and electricity grids. As a new combination with heavy upfront capital costs, any form of traditional standardization makes sense for both sides. And to prevent lock-in effects, the earlier the better (see 'entry deterrence' in Matutes and Regibeau, 1996). However, at some point the market shifts from the innovation phase to market adaptation and stabilization phases (Filipović, 2013). At that point the reverse is also true: once parties have accepted and implemented a standard, they have an interest to promote their standard and prevent new ones to surface. This is the case with the EV charger types, where there is too much resistance and path dependency to further standardize the three remaining types into one global charger (Bakker et al., 2015). Instead, the industry adapts by designing adapters and multi-charger EVSEs.

#### 4.3 Interoperability and scalability

The scalability and interoperability that a standard like ISO 15118 enables often pose the reason to strive for standardization. Evidently, ISO 15118 allows for the interoperability between two different sociotechnical systems (transport and electricity) and subsequently allows these entities to scale up their production and output for an integrated system and a broad implementation with minimal risk of sunk investments. Equally important, however, from a V2G and grid perspective is that ISO 15118 allows for the scalability and introduction of huge numbers of EVs on the electricity grid as it provides for a way to communicate between them and the rest of the grids in order to prevent them from charging all at once.

That said, while ISO 15118 standardizes the communication between EVs and EVSEs, it can only act in the benefit of the grid when we look at it as a ‘nested’ standard. More precise, the only way that EVs are (dis)charging in the benefit of the grid is if the utilities can simultaneously communicate with multiple EVSEs and their connected EVs. ISO 15118 is part of this equation, but the system also includes the subsequent back office applications or second tier communication protocols, which allow for communication across EV fleets and EVSE operators. In this respect, both the USA and European cases highlighted the role of the second tier Open Charging Point Protocol (OCPP) and subsequent third tier Open Clearing House Protocol (OCHP). An added benefit of these latter protocols, especially the third tier is ‘to make sure that PEV drivers can really get their cars charged anywhere they want (Buamod et al., 2015, p. 1).’

Just as ISO 15118, these back office protocols also offer new social roles and functions. For example, for the grids, aggregators are an essential and much discussed new role as they allow for blocks of EVSEs and fleets of EVs to partake in the bidding process of electricity markets. For consumers, in turn, the so-called ‘clearinghouses’ are an important new role as they allow EV consumers to roam (charge and pay) with companies in regions other than their own. To organize the communication between charger operators, the Dutch company *ElaadNL* (its frontrunner *e-laad*) and the Belgian operator *Blue Corner* joined with the German *ladenetz.de* network to create *e-clearing.net*. This clearinghouse is a non-profit service provider that manages a set of servers and the software that keeps track of charging transactions and the contracts behind them. In doing so, it pushes forward its own open source code and protocols (OCHP) to those companies who want to join in. By now, 18 companies make use of this clearinghouse, enabling the roaming of 9500 public chargers across 11 countries (e-clearing.net, 2016). Here again we see a negotiated and political process, as e-clearing.net is not the only clearinghouse under development. Yet, open conflict is not an automatic result of these processes: as of March 2015 multiple clearinghouses in Europe have agreed to cooperate (e-clearing.net et al., 2015).

In terms of the manner in which standards become effective it is interesting to notice the difference between ISO 15118 and second tier standard OCPP. For even though ISO 15118 is an official global standard that is renegotiated and facing resistance, the OCPP back office protocol is meanwhile emerging as a *de facto* international standard for back office communication (eMI3, 2015, p. 13; Martinenas et al., 2016, p. 3). Where

ISO 15118 is formally negotiated and implemented, the OCPP standard (like CHAdeMO) is emerging from the bottom up, from the markets themselves. Both standards thus gain in interoperability and scalability, but they draw their authority and popularity from two different processes. ISO 15118 draws from its internationally negotiated nature, while OCPP draws from its open source nature in contrast to its proprietary competitors.

#### 4.4 Transnational cooperation and governance

Section 3 showed how an international standard is implemented differently in different geographic regions. Being a standard – instead of a regulation or international agreement – means that this is not a weakness per sé. Instead, the constant renegotiation is part of what makes standards effective: while creating a stable footing, they offer space for development and innovation. Those companies that cannot compete know what to expect, while those that judge that they can (or need to) move into another direction can do so. Moreover, as standards are market focused they work in the grey area between national and international regulations. In a way, the current case selection only does this process partly justice, as it focusses on the differences and connections in-between countries instead of regions or companies. Two remarks can be made regarding cooperation.

First, this paper observed the need for standards in the electric mobility industry, with charging companies trying to prevent sunk costs and car companies favouring standards that increase their production efficiency across different administrative regions with different design, safety and environmental regulations. Simultaneously, section 3 highlights a number of individual companies which set their own standards. Explicitly, for instance, in case of Nissan's success with the CHAdeMO standard or in the case of the OCPP protocol. But also implicitly, as in the case of the company Nuvve, which is a frontrunner in applied V2G projects and is active in both the USA, Denmark and the Netherlands. Consequently, it exports at least parts of its software, with corresponding design choices (including which standards to use and how to use them) across these countries (Nuvve, 2016).

Second, governments play an important role in standardization practices as enablers of industries and standardization bodies, by offering indirect financial, regulative or diplomatic support in favour of a standard (whether domestic oriented or international). The Dutch government financially supported the initiation of a Dutch

working group on EV standardization specifically with the aim to enable Dutch company representatives to participate in European and international standardization meetings. Likewise, on an international level, the American and Chinese governments agreed in 2009 on a joint USA-China Electric Vehicles Initiative, also with standards as a core pillar (Brown et al., 2010; The White House, 2009). This international dialogue is since opened up to other countries (Clean Energy Ministerial, 2016) but both countries remain in bilateral contact through the American National Standards Institute China program (ANSI, 2016). All of this in addition to the official ISO and IEC meetings.

Striking when reflecting from the outside on these different forms of international and transnational collaboration on ISO 15118 is the relative absence of other Asian countries, in particular Japan and South Korea. Although these countries actively partake in the ISO 15118 discussions and section 3.2 showed the importance of the Japanese CHAdeMO standard for V2G projects, most of the public discussion on ISO 15118 is not focused on Japan. In fact, the choice for certain technical requirements and protocols within ISO 15118 explicitly excludes the CHAdeMO standard, even though this standard is quite prevalent for DC charging.<sup>5</sup> This is confirmed by an early preliminary study of Filipović (2013), who looked into three different Western standardization meetings and their roadmaps to see which available EV related standards were mentioned (focusing on 2009 standards). Filipović concludes that only a small number of non-western standards were mentioned and that the meetings were primarily centred on local and regional standardization needs. This confirms the need for international discussions, but also highlights the political and localized nature of the decisions to use standards, as well as the inherent winners and losers that come with such a choice.

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<sup>5</sup> For DC charging, ISO 15118 is based on an early German communication standard (DIN 70121) and so is the American SAE J2847/2. All three are usable for type 2 Combined Charging Systems (CCS) connectors and based on a PLC instead of CHAdeMO's CAN. During review we learned (IEA, 2018) that Japan has decided on SAE J1772 type 1 for slow chargers (plus Tesla) and accepts *all* DC standards. Korea instead allows only type 2 slow chargers and prefers CCS Combo 1, but like other countries accepts CHAdeMO as well.

## 5 Conclusion

Standards play an important role in the energy transition and the development of EVs and V2G technology. Their voluntary and constantly renegotiated nature means that they are less visible than official regulations and political decisions, but thereby also function as the glue that hold many aspects of the energy system together. It is precisely this voluntary nature that makes standards work. To close the discussion of ISO 15118 the paper offers four broader insights.

First, obviously, V2G standards within the industry are not static, but constantly evolve and are continually adapted. They need to be in a fast-moving industry where the technology is changing rapidly and the adoption and commercialization of EVs dictates increasing coordination and harmonization. For some, this implies a dull technocratic repetition, for others it is a dynamic political process that never ends (Gorur, 2013, p. 133; Timmermans and Epstein, 2010, p. 83). However, the fact that standards cannot be studied solely as a form of rule following, with the punishment of rule breakers, does not mean that they are less important for modern society. We call upon the literature to take the more technocratic and invisible standards as serious as the general standards set by international institutions on for example financial practices (Bowden and Seabrooke, 2006), process and safety standards in the nuclear industry (David and Rothwell, 1996), or outcome standards on energy efficiency and environmental impact (Laskurain et al., 2015; Williams et al., 2016).

Second, much like the ‘nested’ scale at which the automotive industry operates, V2G standards across China, Denmark, the Netherlands and USA are neither purely ‘local’ nor ‘global.’ Instead they are prone to what Woywode (2002) has termed a process of ‘local adaptation’ where international standards become refined and redeployed in a particular local context. Similarly, our research confirms findings from Abo (1995, 1994) speculating that management concepts must always be adapted to existing cultural conditions to work, creating a so-called ‘hybrid’ consisting of both international and local elements. This paper shows how semi-autonomous, local groups have the freedom to decide on whether they follow an international standard. And once they have decided, how to fit these standards in existing social and technical contexts. Standards are not decided purely upon their technical qualities, and the ‘best’ standard for one party might not be the best for another.

Third, we like to draw attention to the inherent assumptions and scripts that are built into a standard, as in the assumptions about EV drivers and the resulting new organizational roles of clearinghouses and aggregators. These hint at the social as something that is coproduced (Jasanoff, 2004) within the seemingly technocratic communication standards. In other words, there is an ethical dimension to the setting and translation of standards. Sometimes this is referred to as the monopoly position that economists describe (Matutes and Regibeau, 1996) or the power of some countries to dominate markets (the globalization literature). We feel that the role of political and social scientists is not to judge these – how to judge whether the total benefits of a standard outweigh the absence of one or the wrongful implication of another – but to bring to light that there are social implications for the networks to reflect upon.

Fourth, while we have used this opportunity to flesh out a number of important and quickly overlooked social and political implications of a technical standard like ISO 15118, we have no doubt that ISO 15118 is in fact an important technical and political achievement. Even with its fragmented implementation, between countries and within them, ISO 15118 allows for an interoperability between two formerly separated industries and a subsequent potential scalability of EVs that is required for a further transition of our transport system away from fossil fuels. What is more, it acts as a benchmark for the standards and technological developments yet to come – transforming not only devices, but the ways that people interact with them.

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